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TM-1415
2961.200

AN "ECONODUMP" DESIGN[1] FOR THE FERMILAB DIRECT NEUTRAL LEPTON FACILITY

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August 1986

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An extensive effort has been directed toward a major redesign of the Fermilab Direct Neutral Lepton Facility (DNLF).[2] The goal has been a very significant cost reduction of the facility, with minimal sacrifice of physics potential. Hence the name "Econodump" applied to the redesign effort.

DESIGN CRITERIA

To achieve the stated design goal, the following criteria have served as guidelines:

Use of existing components where feasible

A major cost in DNLF was the very large spoiler magnet system, designed and to have been constructed especially for DNLF. Utilization of existing magnet components, if feasible, could allow for a much less expensive facility.

Additionally, the proposed DNLF pretarget primary beam enclosure with extensive dipole and quadrupole components was a significant expense for which alternatives might be feasible.

A limit on background muon flux at each bubble chamber of no more than 300μ's$/10^{13}$ protons

The DNLF spoiler magnet design was predicted to give fewer than 10 muons/10^{13} protons.[3,4] Each chamber however is believed to be capable of resolving events without significant efficiency loss with 50 to 100 muons traversing the liquid during expansion. Due to significant uncertainties in modeling muon production and transmission through the active spoiler magnet shield, the DNLF design was very conservative in this regard. This degree of design safety achieved in DNLF was a major factor in the spoiler magnet size and hence cost.

1E13 900 GeV Protons/TeV Cycle in 3-5 Beam Pings

Tevatron accelerator capabilities indicate a probable practical limit on available protons for the neutrino program of about 1E13 protons/TeV machine cycle. This can readily be provided in a sequence of beam pings during the ≥20 second ramp flattop, with spacing of the pings determined by bubble chamber deadtimes.

The Tohoku chamber can accept a repetition rate of five seconds (5 pings) while the present viable rate for the 15 foot chamber is 10 seconds (3 pings). Hence the design limit of 300 muons/10^{13} protons.

900 GeV is probably a practical energy limit for high intensity Tevatron fast spill resonant extraction for the foreseeable future.

Quantitative understanding of muon production in relevant kinematic regions

An Econodump design with predicted muon rates through the active shield at levels comparable to chamber capabilities loses much of the safety factor present in the DNLF design. We have attempted to compensate by achieving more quantitative understanding of muon production in the kinematic regions which contribute the majority of background muons.

The three computer programs developed to predict background muon rates for DNLF (Columbia, Fermilab, and MIT) agreed very well in calculating transmission efficiencies through a given spoiler magnet configuration; but differed by as much as two orders of magnitude in production spectra used.

Minimal design physics compromise, along with more quantitative event rate projections

A maximum target-detector distance for the Tohoku bubble chamber has been chosen to be 90 meters. The 15 foot chamber would then be at 190 meters. Target to chamber distances in DNLF were approximately 60m. and 160m. respectively.

The necessary $\int Bdl$ and hence expense of the active shield is a strong function of the target-chamber distance.

Event rates are also of course dependent on this distance. This dependence is however much less than that expected from a $1/R^2$ scaling, due to the already significant fall off of event rate with production angle, over the detector fiducial volumes, at target distances considered.

Event rate projections have also been updated for the two bubble chambers, based on data not available when DNLF was initially proposed (Fermilab Beam Dump Experiment 613).

Initial Econodump design orientation toward Tau neutrino search with the Tohoku chamber

Comprehensive background calculations have been accomplished for the Tohoku bubble chamber at a target distance of 90 meters. It is expected that backgrounds for the 15' chamber at 190m. will be comparable. However, at this stage, only a few rates have been modeled for the large chamber. Projected event rates have been determined for both chambers.

ECONODUMP DESIGN

Beam Line

A major cost element for the DNLF primary beam transport was the pretarget enclosure containing 17 dipoles and quadrupoles, which provided the following functions:

A) Line up of the proton beam for zero degree targeting on the NO line, on which the existing neutrino detectors are centered.

B) Provide a large angle bend as near upstream of the target as feasible. This enabled significant reduction of muon and neutrino backgrounds aimed at the detectors from upstream sources: scraping of beam tails and beam-gas interactions.

C) Defocusing of the high intensity proton beam before targeting, to lessen peak energy density deposition in the target. This is especially important for very high Z targets, such as tungsten.

D) Enable different targeting angles (0 to 40mr) for measurements over a large angular region.

For the Econodump design, the primary proton beam is aimed directly at the 15 foot bubble chamber from Enclosure NE8, as shown in Figure 1. The DNLF design is shown for contrast in Figure 2.

In the Econodump, the Tohoku chamber would be shifted laterally in Lab F (a simple task) to again centrally intersect the targeted primary beamline. This line would intersect the Lab C detector off center, as seen in Figure 1 and, in finer detail, in Figure 3. As an initial design parameter the proton beam could be centrally targeted for any of the neutrino detectors. Once selected however, this beam trajectory would not be variable.

The larger bend angle required at Enclosure NE8 with the DNLF design necessitated new civil construction and several additional dipoles in the downstream part of the enclosure.

The Econodump targeting configuration requires only a lateral position shift of 7 existing dipoles in NE8 along with the addition of two new elements, as is shown in Figure 4A and 4B. Econodump (NL) beam operation is compatible with slow spill beam to the NEast line. Conversion back to NT/NH beam operation would involve repositioning the seven dipoles.

Defocusing of the primary beam before targeting is greatly simplified with the Econodump design. For DNLF the beam size had to be carefully controlled during transport through the pretarget dipoles, to avoid beam scraping. Then defocusing had to be accomplished with very little distance before the target, requiring a significant number of quadrupoles.

The Econodump has no limiting apertures after NE8, and due to the long lever arm, beam size at the target can be readily controlled with one quadrupole at the downstream of NE8.

Horizontal and vertical beam envelopes as a function of distance along the beamline are shown for Econodump and DNLF in Figures 5 and 6. Upstream of NE8 the beam transports are identical, along existing beamlines.

Downstream of NE8 the Econodump and DNLF both required installation of stainless steel berm pipe through the neutrino berm to the Target Hall. For the Econodump only one pipe is needed, however, as the DNLF variable targeting angle has been deleted.

Elimination of the 40mr targeting option should involve no compromise for the Tau neutrino search, due to projected flux limitations at large angles.

The greatest potential compromise with the Econodump primary beam design is the long decay path of ~ 1200 feet from NE8 to the target, aimed directly at the bubble chambers. This produces concern of large muon and conventional neutrino backgrounds.

Monte Carlo studies indicate, however, that requirements for reduction of beam halo and beamline vacuum are no more severe than for the DNLF design. Results of these studies are presented in a later section.

Target Hall

The Econodump target hall design is similar to that of DNLF, but with several changes which reduce cost without adverse effect on targeting function:

The hall is shortened considerably in length.

A reduction in the earth berm neutron shield over the target has been effected.

DNLF design had a safety factor of 10^5 for this shield.

Support pilings under the hall can be removed due to reduced loading.

The target design for Econodump is a 1.2 meter Cu target, as in DNLF. Space provision for targets of different atomic weight and effective density has been retained.

Figure 7 shows plan and elevation views of the target and spoiler magnet halls for Econodump. For comparison, in Figure 8 are shown the same views for DNLF.

Spoiler Magnets and Hall

For the DNLF design, the spoiler magnets forming the active muon shield represented a very significant fraction of the project cost. With the Econodump, major changes are made in this active shield. The following table shows a comparison of DNLF with the Econodump spoiler magnet system.

Comparison of 216: M1 and SM12-C

To DNLF Proposal Magnets

	M1 177" long	M1 216" long	M2	M3	M4	M5	SM12-C (34"pole)	
Iron weight	540	659	780	1050	1830	1950	1356	tons
Conductor Weight	7.2	8.4	10.4	21.1	32.2	37.2	85*	tons
DC Power	10.7	12.6	15.4	958	1443	1622	1605	KW

*Aluminum Coil

	5 M1(177") $+\Sigma$ Mi i=2	M1(216") +SM12-C	
Iron Weight	6150	2015	tons
Conductor Weight	108	8.4+85*	tons
PC Power	4049	1620	KW

*Aluminum Coil

The five DNLF spoiler magnets, M1-M5, are replaced by only two magnets for the Econodump; a 216" long M1 and the 567" SM12 magnet previously used in E605, reconfigured as a C-magnet.

For DNLF the $\int Bdl$ was 54 Tesla-meters, while with the Econodump design $\int Bdl=42.2$ Tesla-meters. The total iron weight in the Econodump magnetic shield is 2015 tons, compared with 6150 tons for DNLF.

New magnet steel purchase for Econodump is restricted to 659 tons for the lengthened M1 magnet. While M1 is to be built from new materials, the SM12-C magnet requires very little beyond existing materials. The A1 coil is reused intact in the C-magnet configuration.

A detailed comparison of specifications for the two Econodump magnets is as follows:

	M1 (216")	SM12-C	
NI_T	54000	940800	Amp-Turns
N_T	72	196	Turns
I	750	4800	A
Conductor	1.288 x 1.288 x 0.618 inches	2.42 * 2.42 x 0.55 inches	
A_{Metal}	1.36	5.62	$Inches^2$
J_{Metal}	551	854	A/in^2
Inductance	1.28	1.0 (approx)	H
Resistance / Length	6.95$\mu\Omega$/ft @ 150^0 F	2.7$\mu\Omega$/ft @ 120^0 F	
Conductor Length	3195	25755	FT
Resistance	.0223	.070	Ω
$\tau = L/R$	57.35	14.5	s
DC Voltage	16.71	336	V
DC Power	12.6	1605	KW
Weight of Conductor	8.4	85	Tons
Steel Weight	659	1356	Tons
Stainless Steel Weight	6.7	-	Tons

Figure 9 shows a cross-section schematic of the M1 magnet (similar to DNLF except in length). Figure 10 shows a corresponding schematic for SM12-C.

The Econodump spoiler hall is scaled down by approximately a factor of two from DNLF, as is shown in Figures 7 and 8. Corresponding civil construction cost savings are achieved. Due to reduced earth loading, support pilings are no longer needed for the Econodump spoiler magnets.

The new NS5 service building is significantly smaller in both building size and technical support systems required, as power and LCW requirements are reduced considerably for the Econodump design.

A passive iron shield before the Tohoku chamber ranges out muons of momentum up to 7 GeV in the Econodump configuration, comparable to the passive shield in DNLF.

ECONODUMP FUNCTION

Neutrino Event Rates

The Econodump Target-Tohoku Chamber distance of 90m is predicted by J. G. Morfin[5] to lower the tau neutrino event rate by 37% from that predicted for the DNLF configuration. Morfin's study on neutrino and muon rates from a high density beam dump was carried out in parallel with the Econodump design effort.

Figure 20 shows projected $\nu\tau$ interaction rates in the Tohoku Chamber for different dump-detector distances, with 1 TeV protons incident. The parameterization of the Monte Carlo predictions is valid for distances of 20m - 100m. Error bars are the same as in FN434.

Most striking is the relative flatness of the event rate versus distance over the region considered (when compared to the fall-off of a $1/R^2$ scaling). As previously noted, this is due to the significant decrease of event rate with production angle over the detector fiducial volume.

Projected ν_τ interaction rates/10^{18} protons at 900 GeV are 40 events with a chamber distance of 90m and 64 events for the DNLF design. These rates assume Bourquin-Gaillard σ scaling.

The calculations are normalized to the measured E613 beam dump direct neutrino event rates at 400 GeV using high density targets. Although an A dependence was measured in this experiment, it is not critical for the ν_τ rate predictions, as the predictions are based on heavy target data extrapolated to the same.

Major uncertainties in the rate predictions are the $\sigma(F)/\sigma(D)$ ratio, assumed to be 0.1 and the S dependence from 400-900 GeV.

There is some trade off possible between ν_τ event rates and design conservation in increased distance of the Tohoku Chamber from the intense flux, high momentum muon lobes above and below the chamber.

At Econodump target distances of 90m and 190m for the Tohoku and 15 foot bubble chambers respectively, the relative magnetic kick given to high momentum μ's compared to DNLF (taking the shift in bend center of the spoiler magnets into account) is:

Tohoku Chamber - 1.30

15' Chamber - 0.96

Hence the Econodump design is somewhat more conservative than DNLF was for the Tohoku Chamber with regard to this potentially serious background source.

It does not appear feasible to lessen the Econodump $\int Bdl$, as a further cost saving measure, to the distance scaled value of 35 Tesla meters, due to the rapid increase of other muon background sources.

A shortening of the Target-Tohoku Chamber distance from 90m to 75m would increase the ν_τ interaction rate by ~20%.

Muon Backgrounds from Target Production

Two of the three computer programs (MIT and Fermilab) used in predicting muon background rates for DNLF have been used extensively in the Econodump design. The programs have been found to give comparable transmission rates for muons through different spoiler configurations, with differences in muon rates at the chambers predominantly due to differences in the two production models used.

The MIT program was the program used predominantly for final stages of the Econodump design.

All background muon sources considered in DNLF were modeled for Econodump. In addition, for muons scattered deep inelastically, subsequent π production and decay was also considered in the Econodump modeling. This process, which was not considered in DNLF, does produce a contribution to the muon flux at the chamber.

The following table gives calculated muon backgrounds from target associated sources:

Projected Muon Rates for the Tohoku Chamber
Based on MIT Production Model and Spoiler Program

Target, beam dump associated sources;		7 GeV Passive Shield
	Bandpass with Coulomb Scat.	$47\mu/10^{13}$ppp
	Deep Inelastic Scat. (Muon)	9μ
**	Deep Inelastic Scat. ($\pi \to \mu$)	$\approx 20\mu$
	Pair Production (Tridents)	55μ
**	Pole Tip Scat. ($\pi \to \mu$)	$\approx 15\mu$
	TOTAL	$146\mu/10^{13}$protons

** These sources were not considered in DNLF. Results from these processes are preliminary, but are felt to be conservative.

Background muons reaching the Tohoku Chamber are predominantly produced in two separate kinematic regions: low energy and high P_T and medium energy and low P_T.

The contribution labeled bandpass with Coulomb scattering comes predominantly from muons with production energy between 30-80 GeV and P_T 4-6 GeV.

This source gave very little background for the DNLF design, due primarily to much larger vertical good field regions for the DNLF magnets. This was, however, a very expensive solution.

Soft field edges extending beyond the coil of the SM12-C magnet are a significant contributing factor to this background source. Figure 11 shows a cross-section view of the SM12-C magnetic field distribution, and Figure 12 illustrates the field distribution versus vertical position. The soft field edges to the pole region are quite apparent. Figure 13 shows a typical ray trace for this background source.

The second important kinematic region contributing to muon backgrounds is for muon production momenta of 75-225 GeV and P_T of 0-2 GeV. The backgrounds due to deep inelastic scattering and pair production (tridents) are predominantly from this region.

Figure 14 illustrates negative muon ray trajectories for muon momenta between 100 and 800 GeV. Interactions of these muons with the dirt, some of which scatter deep inelastically, is a contributing source of background muons at the Tohoku chamber. To further reduce this background source an inexpensive solution may be a trench between the downstream of the SM12 spoiler hall and the passive shield in front of the bubble chamber.

In Figure 15 is shown a positive muon interacting in the SM12-C pole, with resultant muon pair production, and the negative muon being swept back toward the chamber. As in DNLF the solution to controlling this background source is an air gap for the downstream spoiler magnet region. Optimization for the Econodump geometry indicates the need for an air gap over the full SM12-C length. To optimize $\int$ Bdl the pole gap is tapered, ranging from 3" at the upstream to 12" at the downstream of SM12-C.

The optimal pole gap width and length and subsequent soft field edges, for SM12-C involves a trade off between the Coulomb bandpass and pair production backgrounds. Parameters were adjusted to produce roughly comparable backgrounds from each source (based on the MIT program).

Muon Backgrounds from Upstream Sources

Extensive Monte Carlo studies have modeled the effects of beam halo for the Econodump design. Of particular concern is the long decay space (~1200 feet) aimed directly at the bubble chambers at zero degrees. A crucial design feature is the dirt berm surrounding the beam transport pipe (12" diameter for most of its length). This dirt provides ranging for most beam halo muons in the crucial spoiler magnet bandpass momenta region of 30-80 GeV. High P_T is not required for the bandpass if the muon enters the spoiler magnet system significantly off axis. The berm pipe then provides a collimated halo muon distribution centered around the proton beam center. In this region bandpass rejection of the spoiler system is improved by orders of magnitude.

Figure 16 shows a Monte Carlo output (program HALO) of muon spatial distribution generated by an interaction source in Enclosure NE8 for the Econodump design. Figure 17 shows a corresponding distribution for a similar interaction source with the DNLF geometry. In each case the figures have the same coordinate scales. There is an arbitrary event normalization between the two plots, but the difference in muon spatial distributions at the target is striking.

For the beam cleanliness levels projected as necessary in DNLF, $< 1 \times 10^{-7}$ of beam in halo at NE8 and 10^{-5} torr vacuum levels in the pipe downstream of NE8, we obtain a projection of $< 10\mu/10^{13}$ protons at the Tohoku Chamber for the

Econodump design. By contrast, were the dirt berm not present between NE8 and the target, the projected number becomes $1200\mu/10^{13}$ protons.

Non-prompt neutrino backgrounds from upstream interactions and decays are negligible compared with target sources for the beam halo level projected.

Muon Production Model Comparison with Data

As the Econodump design does not allow for a large safety factor in muon background rates, it becomes imperative to achieve better quantitative understanding of muon production in the critical kinematic regions.

Figure 18 and 19 show a comparison of the MIT and Fermilab μ^+ production formulas with data of Bodek et al. at 350 GeV. Comparisons are made both of P_μ and P_T distributions. A similar comparison was made in TM1155R[4] with high P_T data of Cronin et al. at 300 GeV. In all cases the MIT production model predicts rates significantly above the data. A comparison of the MIT model with preliminary E605[6] muon data at 800 GeV indicates that in the region of comparison - high P_μ and low P_T - the muon flux predictions are higher than the data by ~ a factor of 10.

There is concern however, due to the manner in which S dependence is incorporated, that this model does not present conservative flux numbers for high P_T and primary momentum significantly above 400 GeV. This is augmented by the muon flux predictions of Morfin in FN-434.

In the critical kinematic regions for muon background sources the following flux ratios are obtained by comparison between the Morfin/MIT production models.

P_L (GeV)	P_T (GeV)	Morfin/MIT
35 - 40	4.8 - 5.3	3.0
55 - 60	5.3 - 5.8	2.15
75 - 85	0.0 - 2.0	0.67
145-155	0.0 - 2.0	0.33
215-255	0.0 - 2.0	0.31

If the MIT model results for background muons at the Tohoku Chamber are normalized to the Morfin predictions, the projected background muon flux would become $\sim 160\mu/10^{13}$ protons with 76% of this background from the Coulomb bandpass.

There are still available several design options which should not increase the Econodump facility cost, which could selectively improve muon rejection in this bandpass region.

During the next Fermilab fixed target run there may be the possibility of measuring the high P_T muon rates in the critical bandpass region-perhaps with the E772 setup.

Econodump Facility Costs

The following table shows the results of a comprehensive "bottoms up" cost estimate for the Econodump facility. A factor of three reduction in facility costs is projected when compared to DNLF, with minimal reduction in physics potential.

COST ESTIMATE OVERVIEW

The cost totals associated with the civil construnction and with the technical components planned for the Econodump Facility are listed below: **(Bold print gives for comparison the D.N.L.F. cost totals.)**

Description	TOTAL with 15% O & P	TOTAL with Escalation	TOTAL with E.D.I.A.	TOTAL with Contingency
CIVIL CONSTRUCTION				
Beam Pipe, Berm & Enc. NE8	$543,700 **$701,000**	$610,000 **$787,000**	$683,200 **$945,000**	$819,800 **$1,135,000**
Lepton Halls & Service Building NS-5	$1,506,800 **$3,094,000**	$1,692,100 **$3,609,000**	$1,895,100 **$4,330,000**	$2,274,100 **$5,195,000**
H-Piling & Earth Retention	---- **$267,000**	---- **$313,000**	---- **$375,000**	---- **$450,000**
Subtotal	$2,050,500 **$4,062,000**	$2,302,100 **$4,709,000**	$2,578,300 **$5,650,000**	$3,093,900 **$6,780,000**
TECHNICAL COMPONENTS				
Beam Transport System	$455,900 **$1,248,000**	$490,000 **$1,375,000**	$504,800 **$1,650,000**	$605,800 **$1,980,000**
Target System at Lepton Hall	$414,100 **$482,000**	$445,200 **$531,000**	$458,500 **$640,000**	$550,200 **$770,000**
Spoiler Magnets	$1,283,300 **$4,956,000**	$1,379,600 **$5,436,000**	$1,421,000 **$6,520,000**	$1,705,100 **$8,470,000**
Subtotal	$2,153,300 **$6,686,000**	$2,314,800 **$7,342,000**	$2,384,300 **$8,810,000**	$2,861,100 **$11,220,000**
TOTAL FACILITY	$4,203,800 **$10,748,000**	$4,616,900 **$12,051,000**	$4,962,600 **$14,460,000**	$5,955,000 **$18,000,000**

<u>References</u>

1) Essential contributions to the Econodump design have also been provided by D. Cossairt and L. Koller, of Fermilab, S. Oh of Duke University, and M. Peters of Univesity of Hawaii.

Engineering design is a result of the efforts of L. Beverly, R. Doyle, R. Fast, C. Federowicz, A. Guthke, C. Kendziora, L. Kula, J. Lindberg, W. Nestander, M. Notarus, T. Pawlak, R. Sanders, and J. Western, all of Fermilab.

2) Fermilab Direct Neutral Lepton Facility Conceptual Design Report, May 1985.

3) C. Baltay et al., The Design of the Magnetized Muon Shield for the Prompt Neutrino Facility, Fermilab TM-1155, October 1982.

4) T. Murphy et al., Magnet Design Study from the Conceptual Design Report for the Direct Neutral Lepton Facility, Fermilab TM-1155R, May 1985.

5) J. G. Morfin, The Intensity and Spectra of Leptons Emerging from a High Density Beam Dump, Fermilab FN-434, July 1986.

6) C. Brown (E605), private communication.

Figure Captions

Fig. 1 Econodump primary beamline from Enclosure NE8 downstream.

Fig. 2 DNLF 0mr primary beamline from Enclosure NE8.

Fig. 3 Econodump primary beam targeting angle with respect to Fermilab neutrino detectors.

Fig. 4 A. Enclosure NE8 in the existing NT/NE configuration.

B. Enclosure NE8 for the Econodump configuration.

Fig. 5 A. Econodump horizontal beam envelope as a function of Z.

B. DNLF horizontal beam envelope as a function of Z.

Fig. 6 A. Econodump vertical beam envelope as a function of Z.

B. DNLF vertical beam envelope as a function of Z.

Fig. 7 Econodump Target and Spoiler Hall

Fig. 8 DNLF Target and Spoiler Hall.

Fig. 9 Cross-section schematic of Econodump M1 spoiler magnet.

Fig. 10 Cross-section schematic of Econodump reconfigured SM12-C spoiler magnet.

Fig. 11 Magnetic field distribution for the SM12-C magnet, as calculated by the program POISSON.

Fig. 12 SM12-C field distribution versus vertical position, along the magnet horizontal center.

Fig. 13 Muon ray trace indicating Coulomb bandpass due to soft field edges.

Fig. 14 Negative muon ray traces for $P_T=0$, $P_\mu=100\text{-}800$ GeV.

Fig. 15 Muon background from pair production.

Fig. 16 Halo muon spatial distribution at the Econodump target for a source at Enclosure NE8.

Fig. 17 Halo muon spatial distribution at the DNLF target for a source also at NE8.

Fig. 18 Comparison of the MIT and Fermilab production formulas with data of Bodek et al. P_μ distribution.

Fig. 19 Comparison with Bodek et al. P_T distribution.

Fig. 20 Projected ν_τ event rate vs. dump-detector distance for Tohoku Chamber, 1000 GeV incident protons.

Figure 1

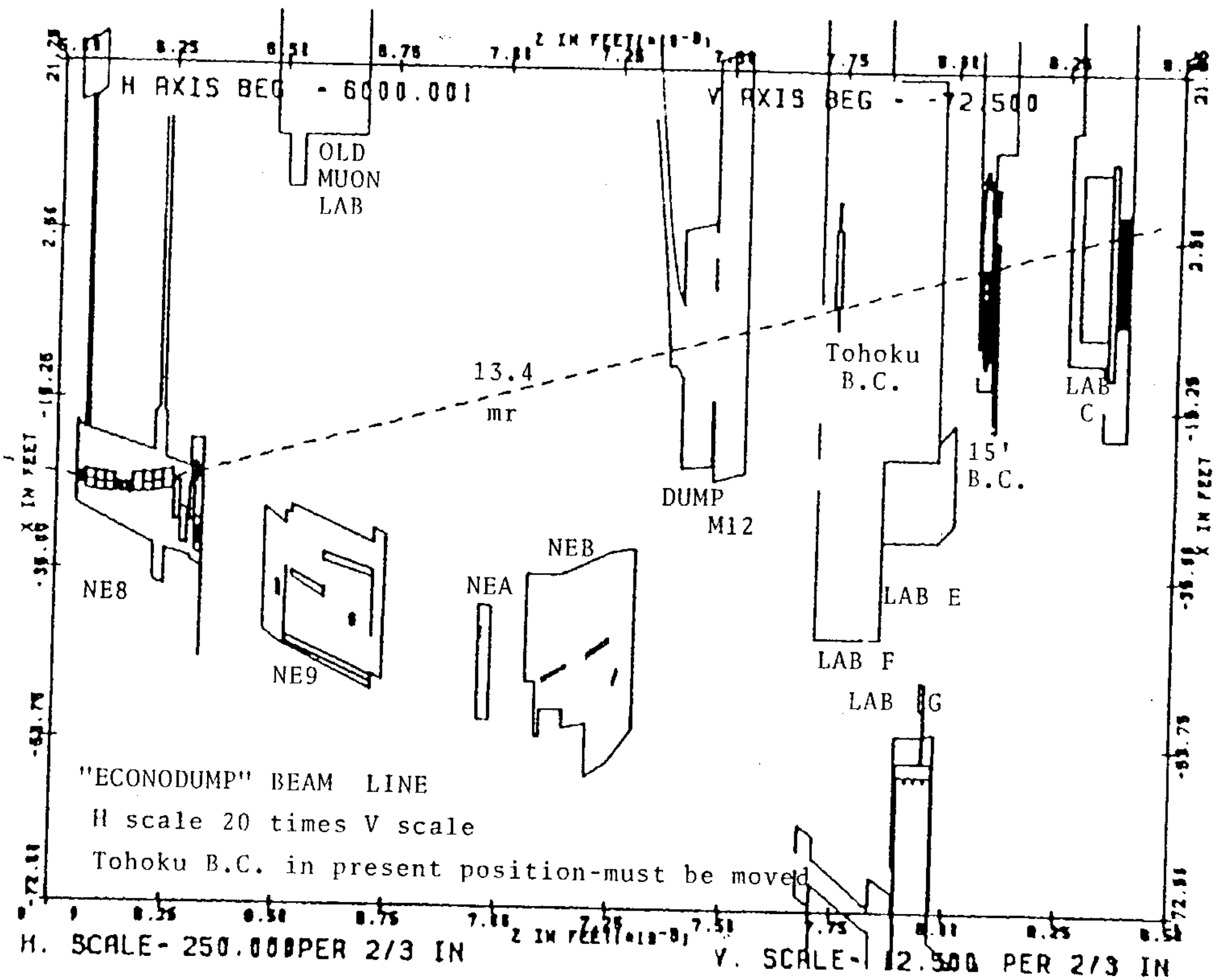

H AXIS BEG - 6000.001
V AXIS BEG - -72.500
OLD
MUON
LAB
13.4
mr
Tohoku
B.C.
LAB
C
15'
B.C.
DUMP
M12
NE8
NE9
NEA
NEB
LAB E
LAB F
LAB G
"ECONODUMP" BEAM LINE
H scale 20 times V scale
Tohoku B.C. in present position-must be moved
X IN FEET
Z IN FEET
H. SCALE- 250.000PER 2/3 IN
V. SCALE- 12.500 PER 2/3 IN

Figure 2

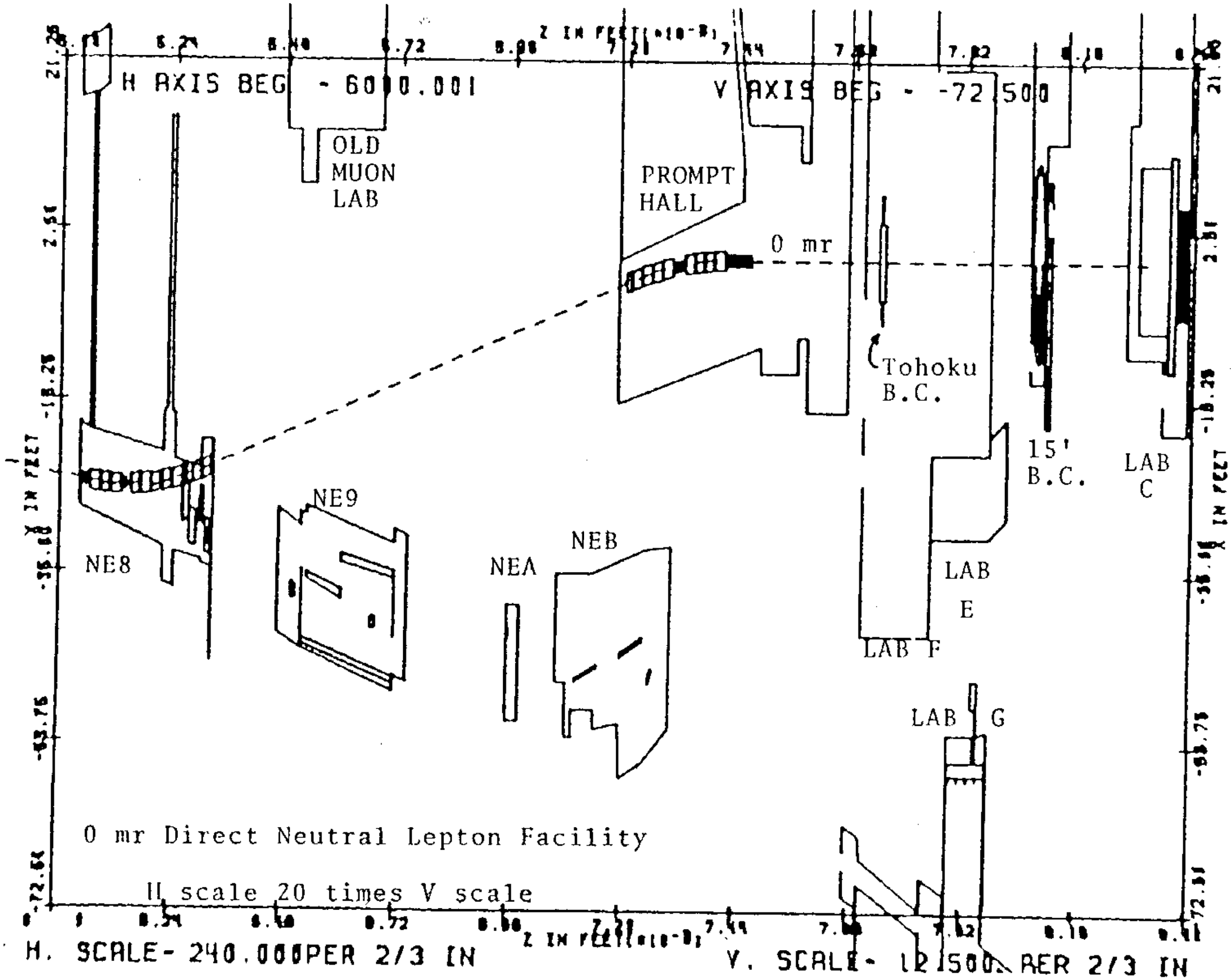

H AXIS BEG - 6000.001
V AXIS BEG - -72.500
OLD
MUON
LAB
PROMPT
HALL
0 mr
Tohoku
B.C.
15'
B.C.
LAB
C
NE8
NE9
NEA
NEB
LAB
E
LAB F
LAB G
0 mr Direct Neutral Lepton Facility
H scale 20 times V scale
Z IN FEET
X IN FEET
H. SCALE- 240.000PER 2/3 IN
V. SCALE- 12.500 PER 2/3 IN

Figure 3

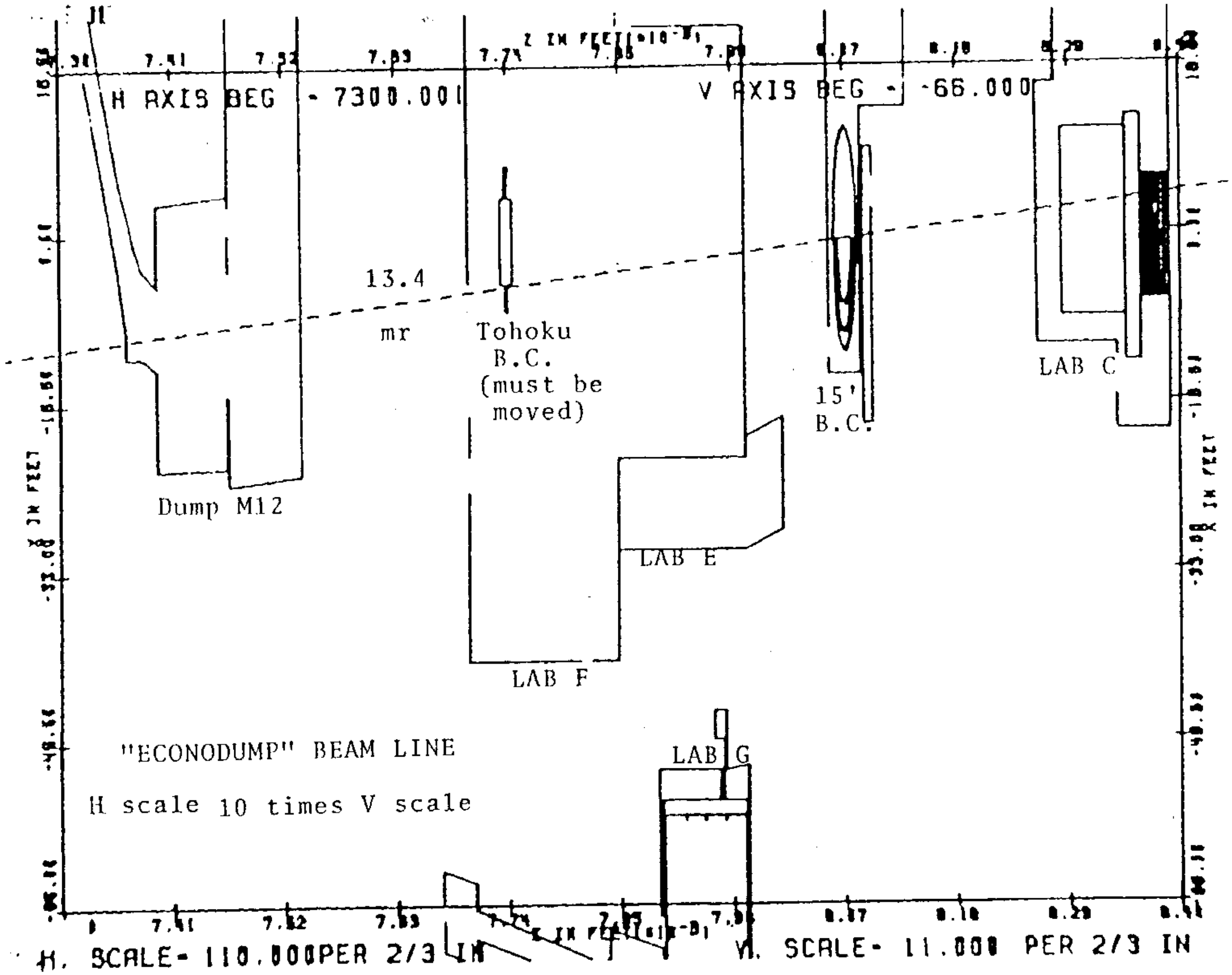

H AXIS BEG - 7300.001
V AXIS BEG - -66.000
Z IN FEET (*10^-3)
X IN FEET
13.4
mr
Tohoku
B.C.
(must be
moved)
15'
B.C.
LAB C
Dump M12
LAB E
LAB F
LAB G
"ECONODUMP" BEAM LINE
H scale 10 times V scale
H. SCALE- 110.000PER 2/3 IN
V. SCALE- 11.000 PER 2/3 IN

Figure 4A

Enclosure NE8 configured in the existing NT/NE configuration. Magnets which must be moved transverse to the beam for use in the "Econodump" configuration are shaded. Note that the 7-th 4-2-240 must be rotated.

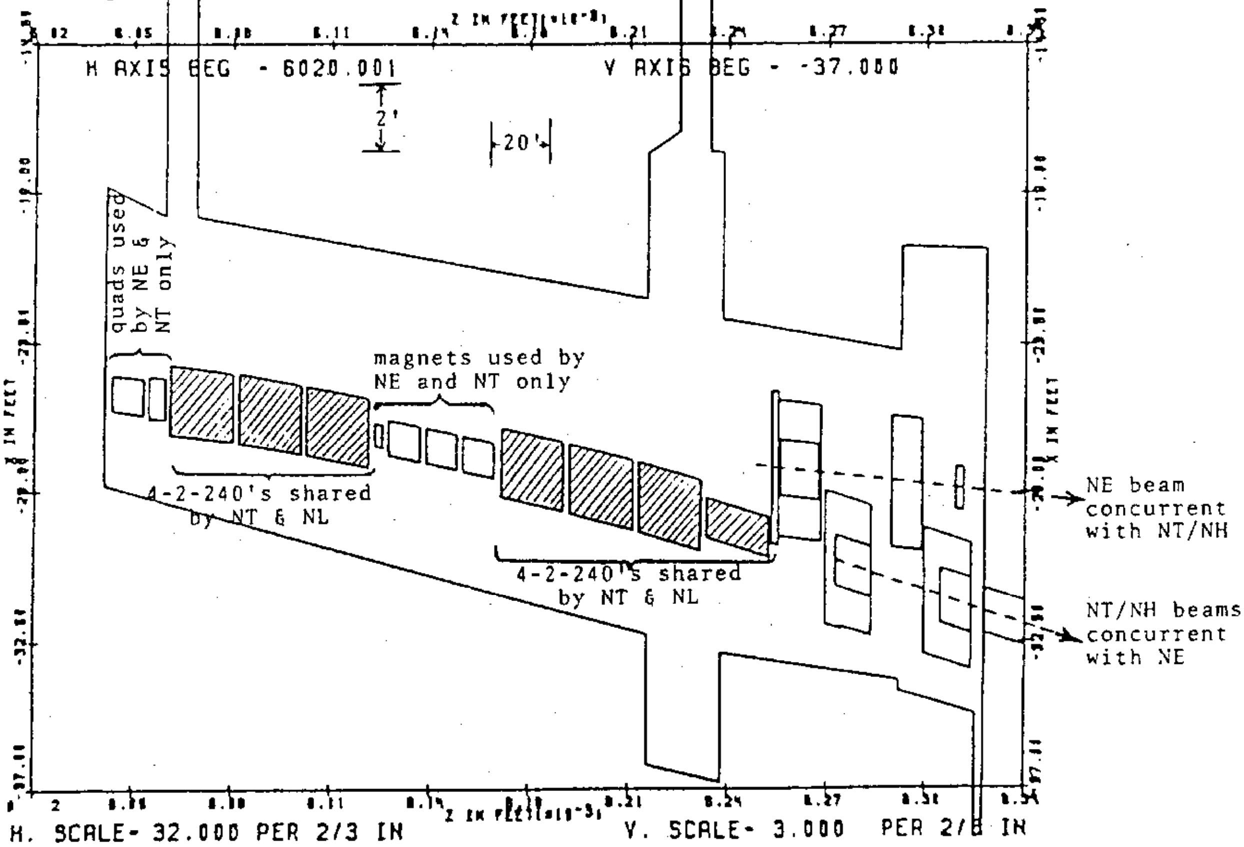


Figure 4B

Enclosure NE8 in the "Econodump" configuration. The magnets used by the "Econodump" beam line are shaded. Distored vertical/horizontal scales.

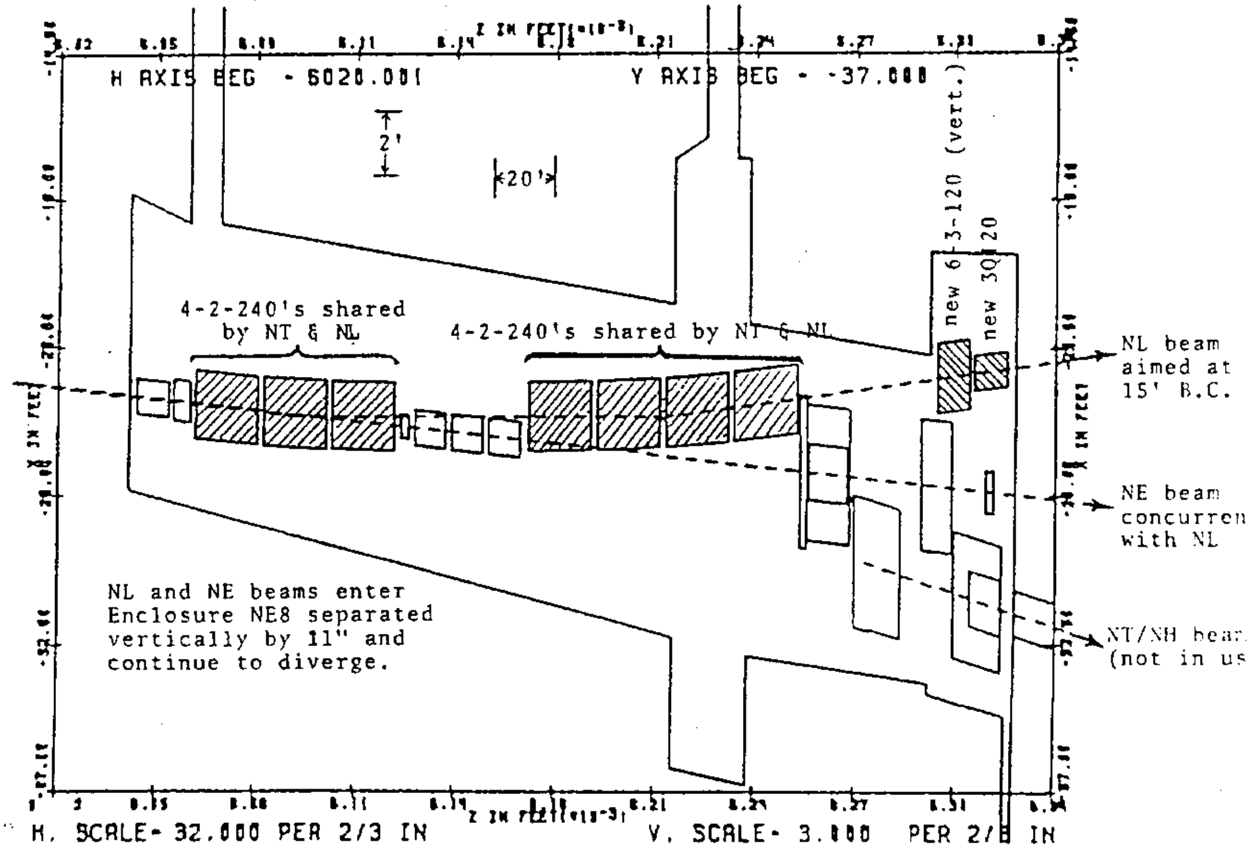


Figure 5A

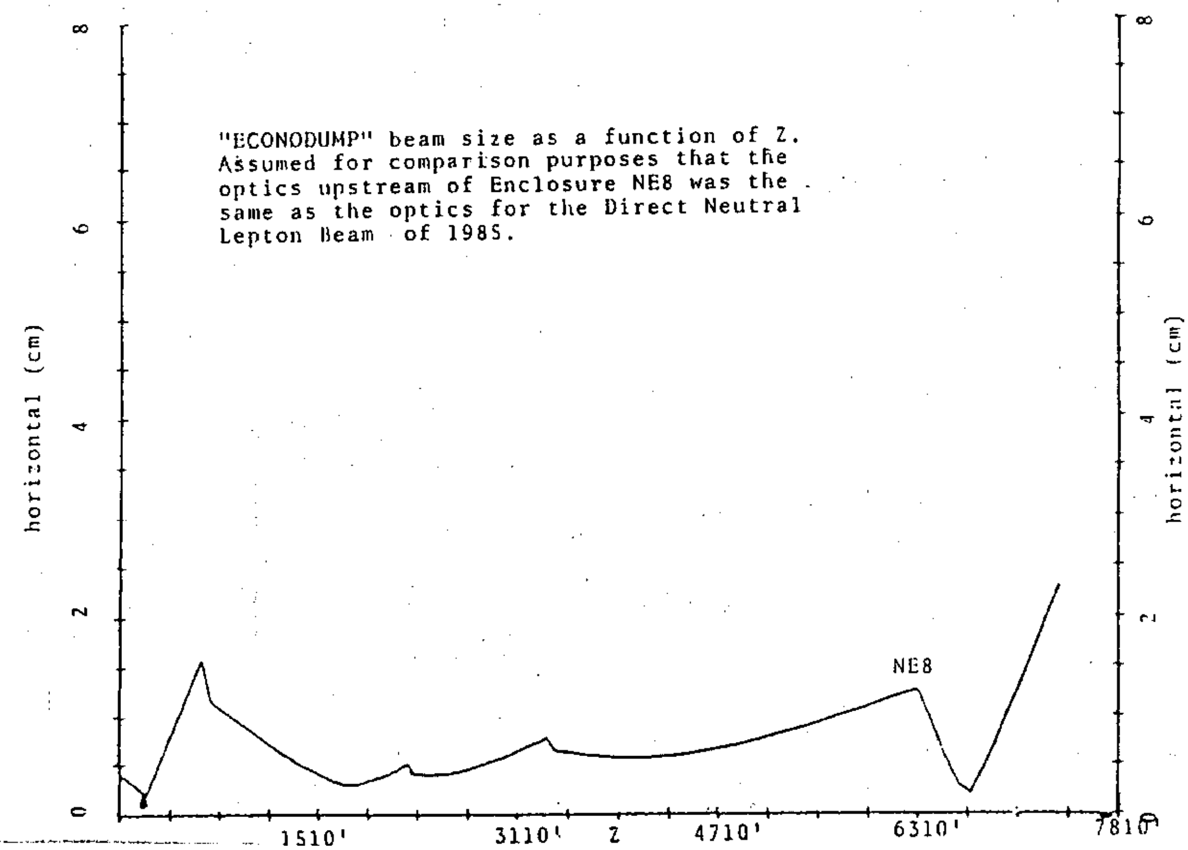


Figure 5B

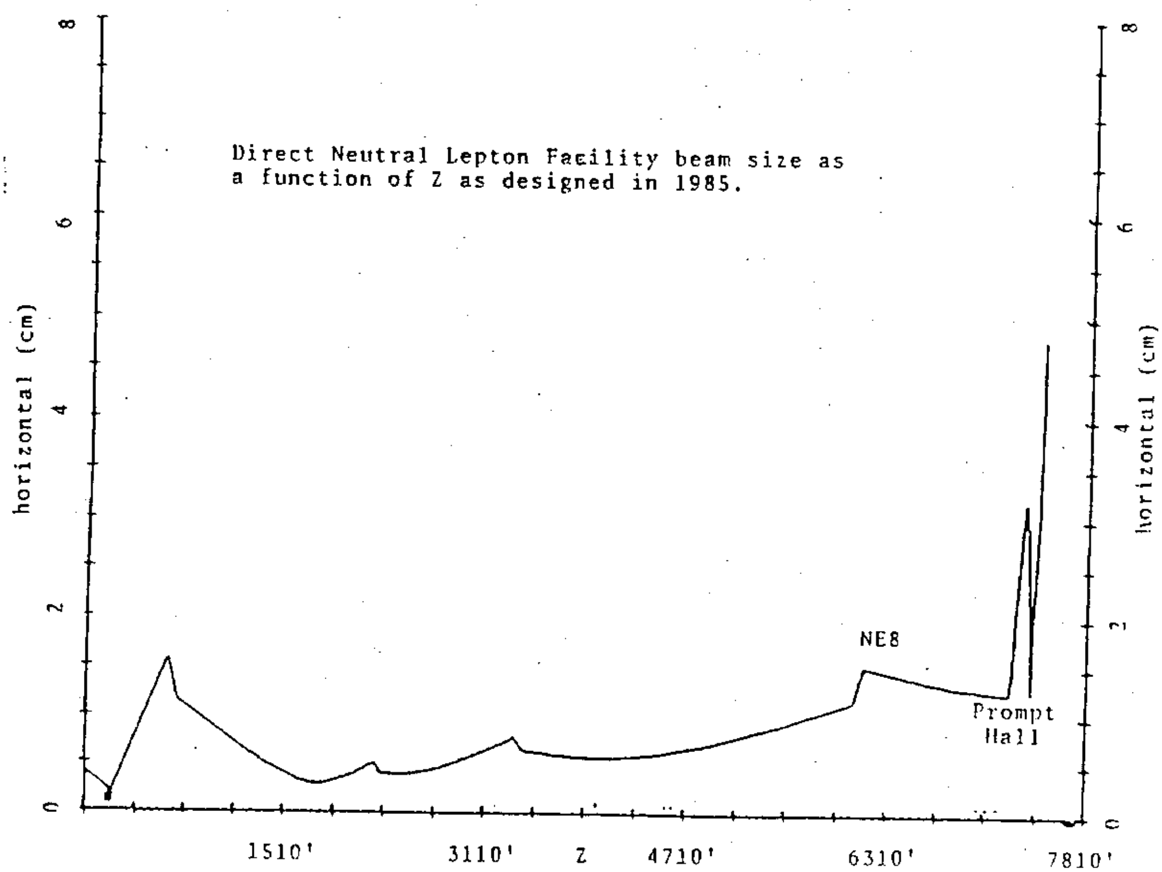


Figure 6A

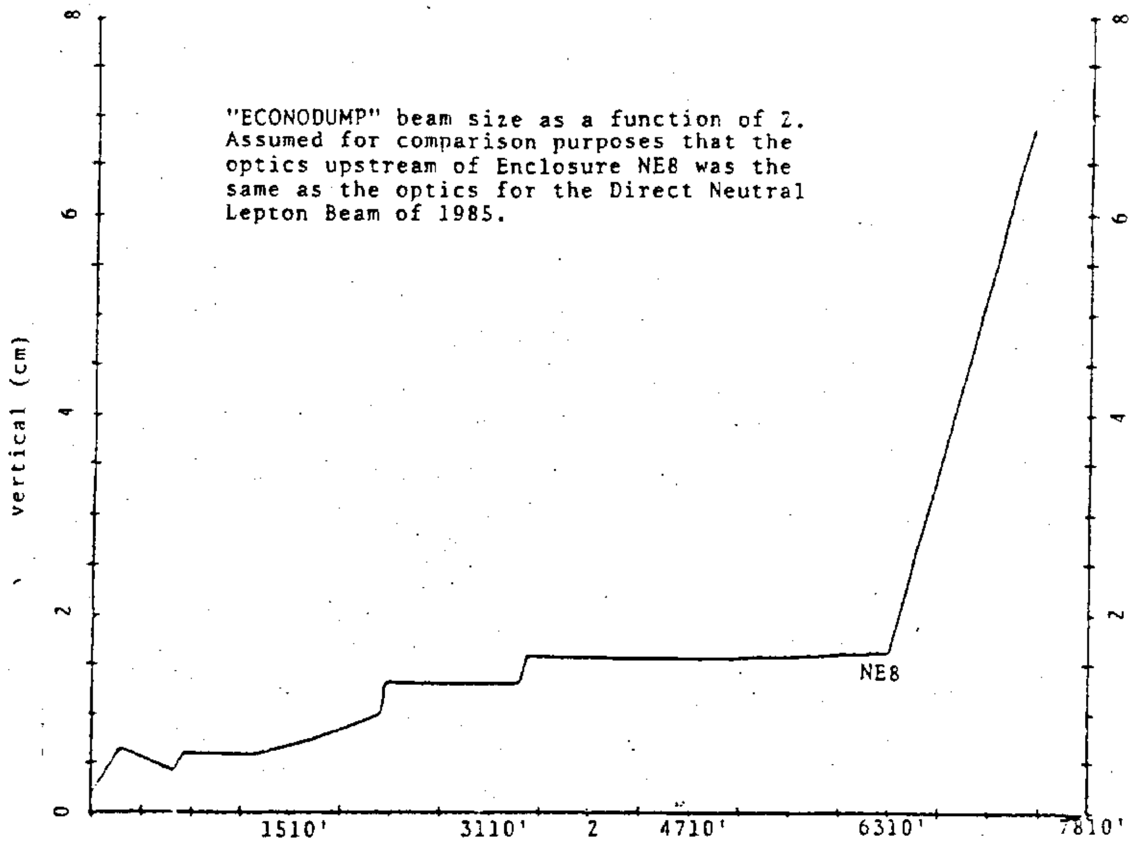


Figure 6B

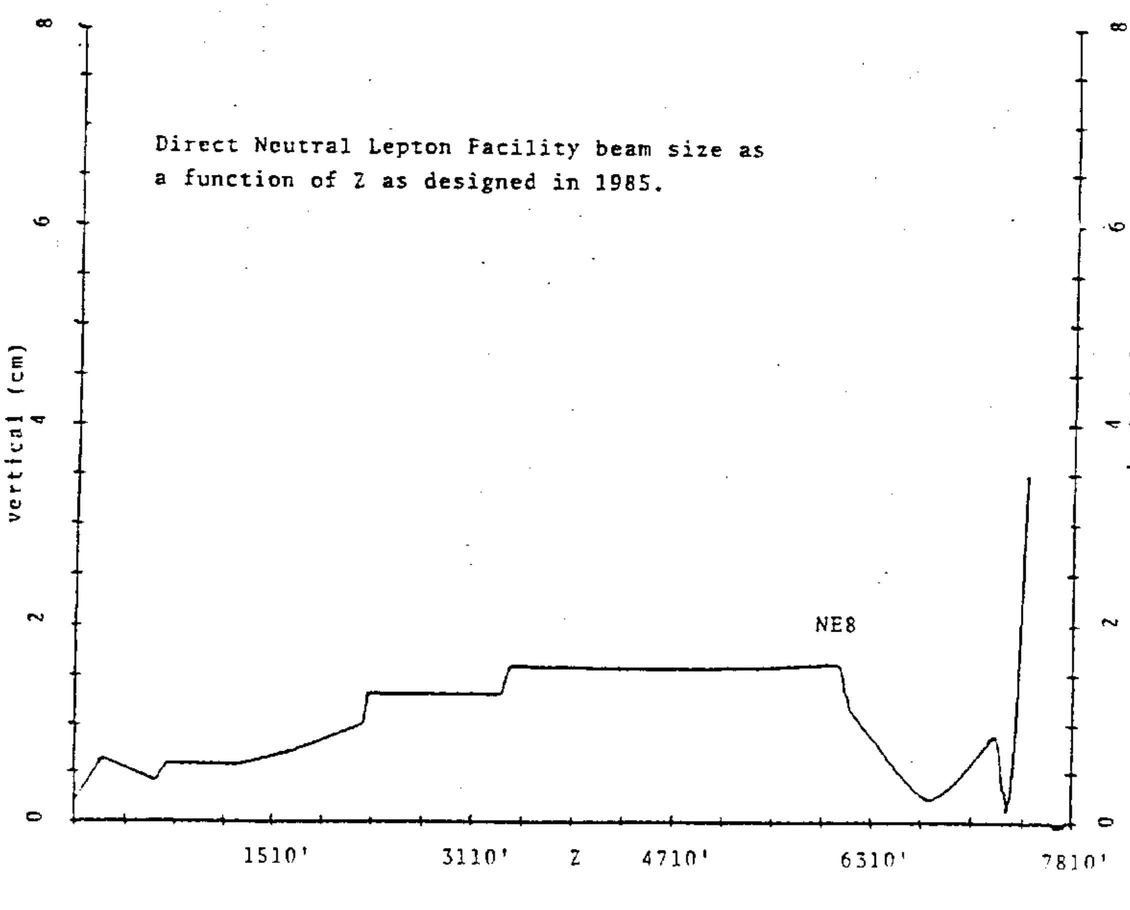


Figure 7

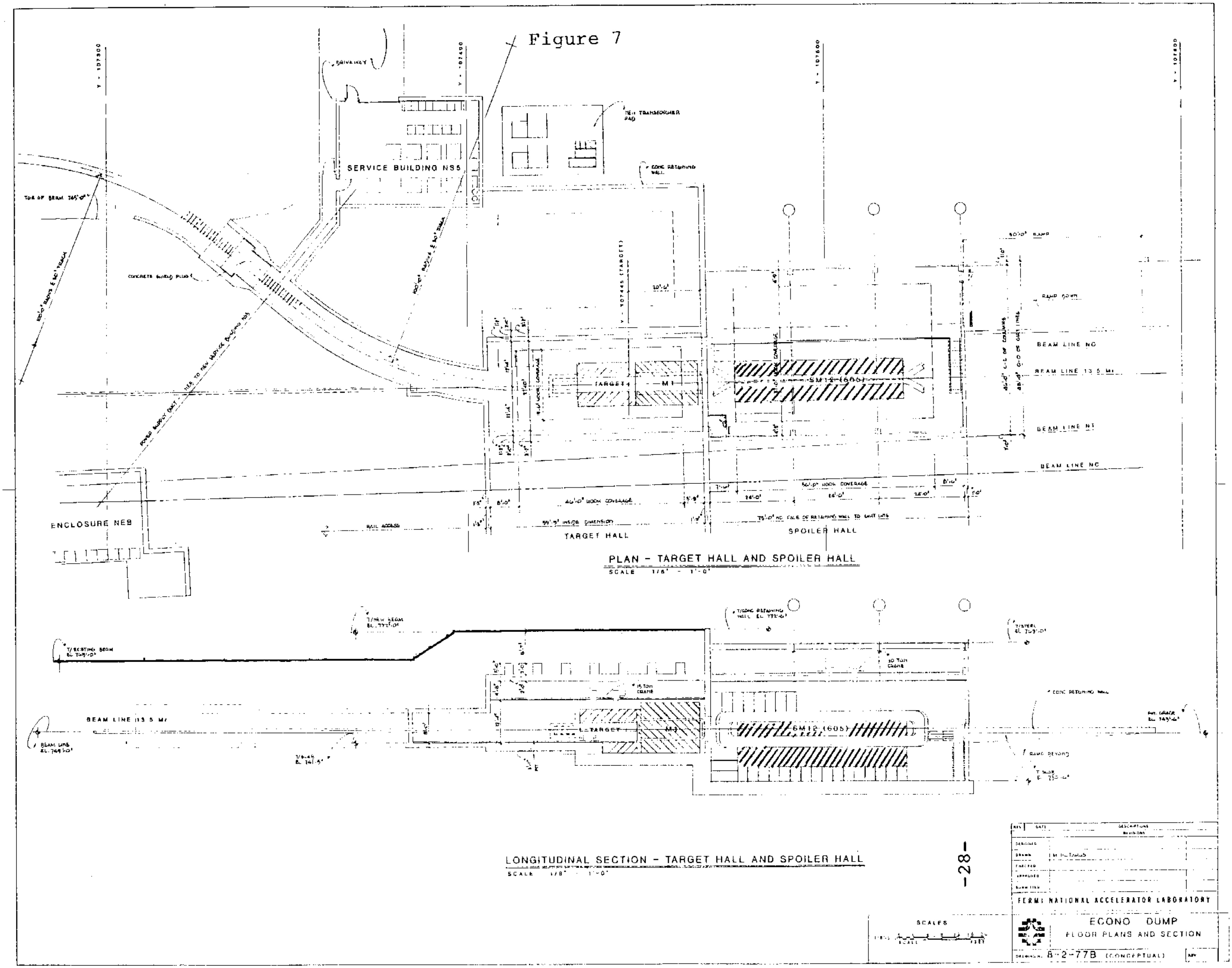

SERVICE BUILDING NS5
ENCLOSURE NEB
TARGET HALL
SPOILER HALL
PLAN - TARGET HALL AND SPOILER HALL
SCALE 1/8" - 1'-0"
LONGITUDINAL SECTION - TARGET HALL AND SPOILER HALL
SCALE 1/8" - 1'-0"
BEAM LINE NO
BEAM LINE 13.5 MR
BEAM LINE N1
BEAM LINE NC
TARGET
M1
SM12 (605)
DRIVEWAY
RAIL ACCESS
SCALES
FERMI NATIONAL ACCELERATOR LABORATORY
ECONO DUMP
FLOOR PLANS AND SECTION
8-2-77B (CONCEPTUAL)

Figure 8

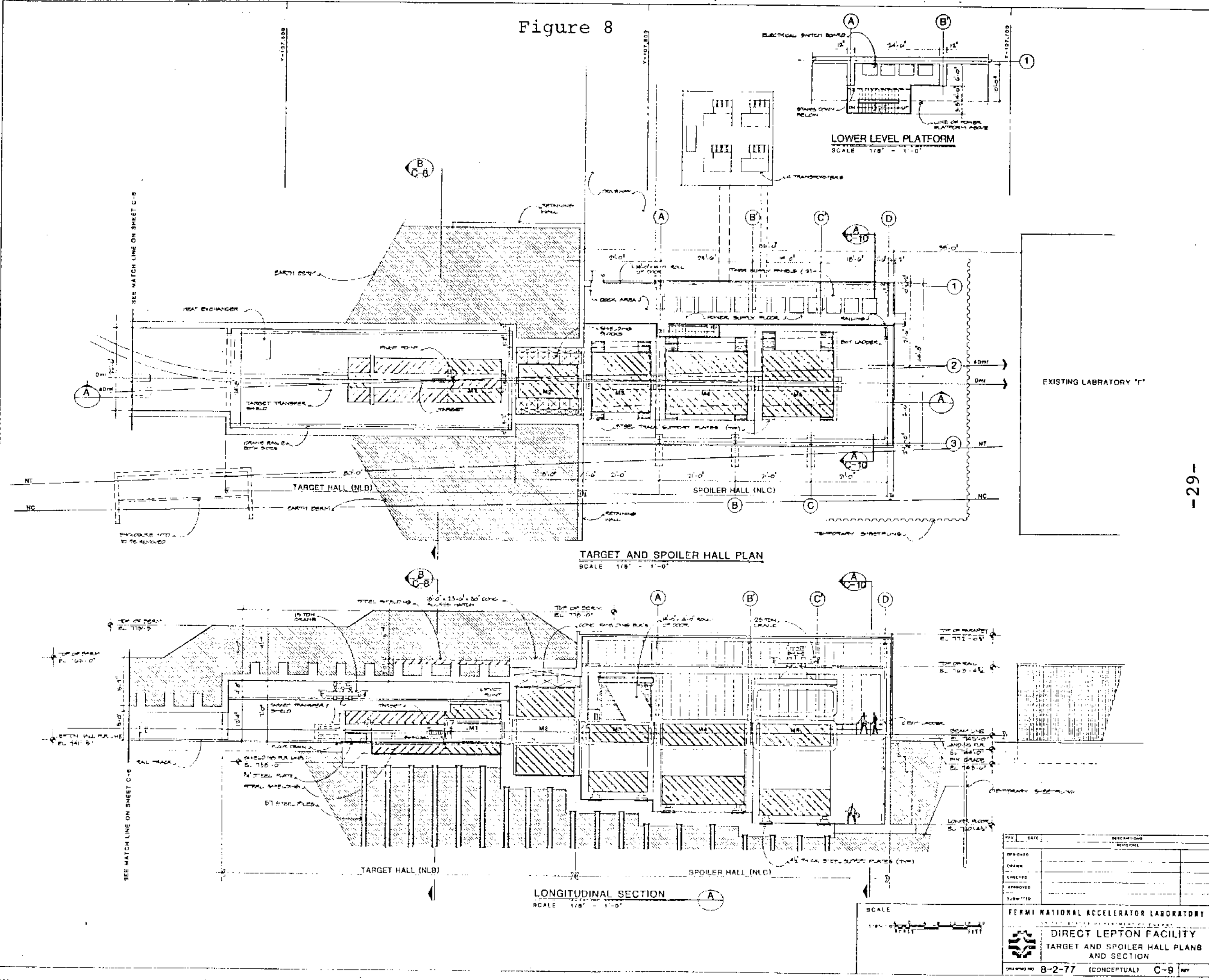

LOWER LEVEL PLATFORM
SCALE 1/8" = 1'-0"
TARGET AND SPOILER HALL PLAN
SCALE 1/8" = 1'-0"
TARGET HALL (NLB)
SPOILER HALL (NLC)
EXISTING LABORATORY "F"
SEE MATCH LINE ON SHEET C-8
LONGITUDINAL SECTION
SCALE 1/8" = 1'-0"
FERMI NATIONAL ACCELERATOR LABORATORY
DIRECT LEPTON FACILITY
TARGET AND SPOILER HALL PLANS AND SECTION
8-2-77 (CONCEPTUAL) C-9

Figure 9

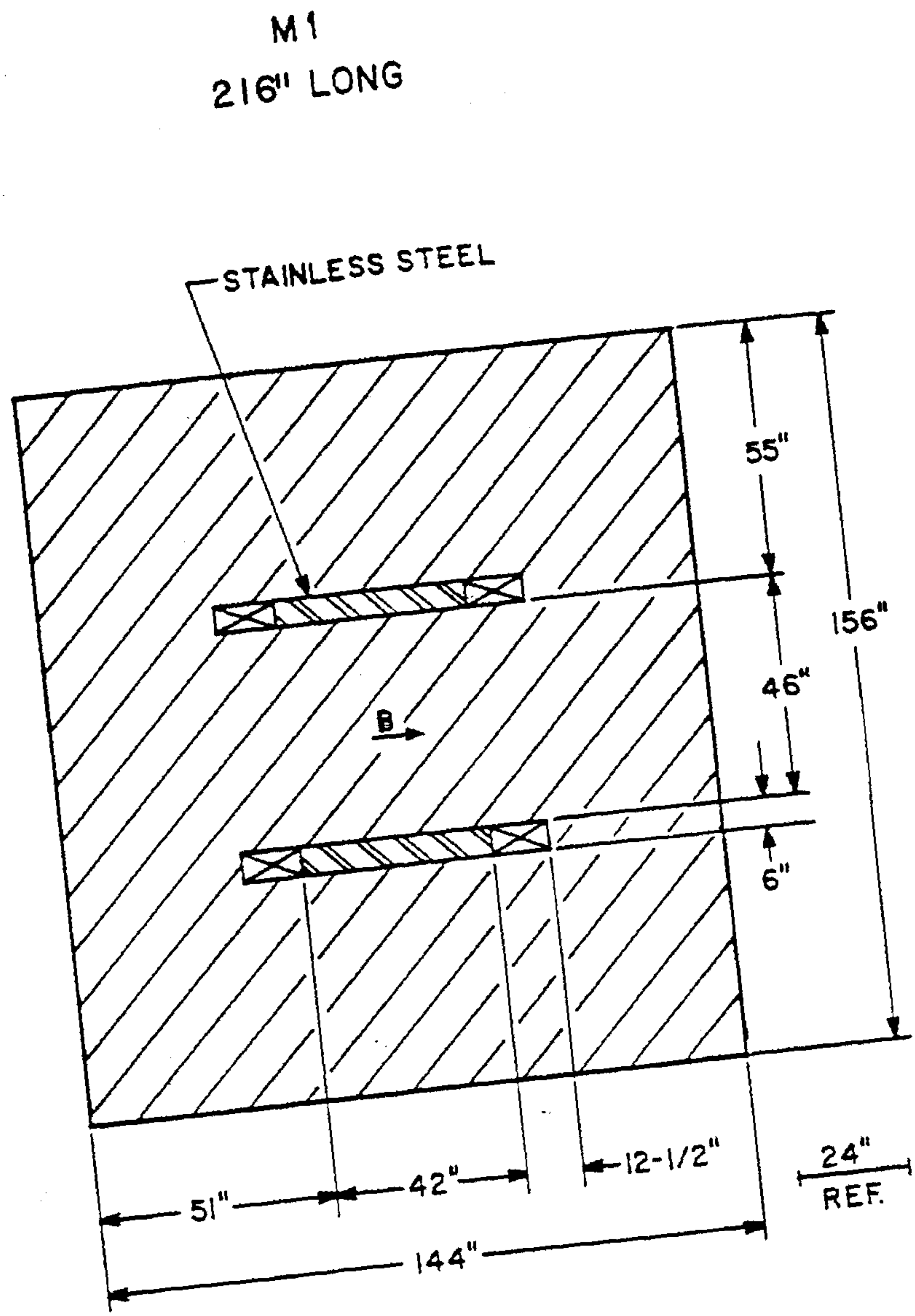
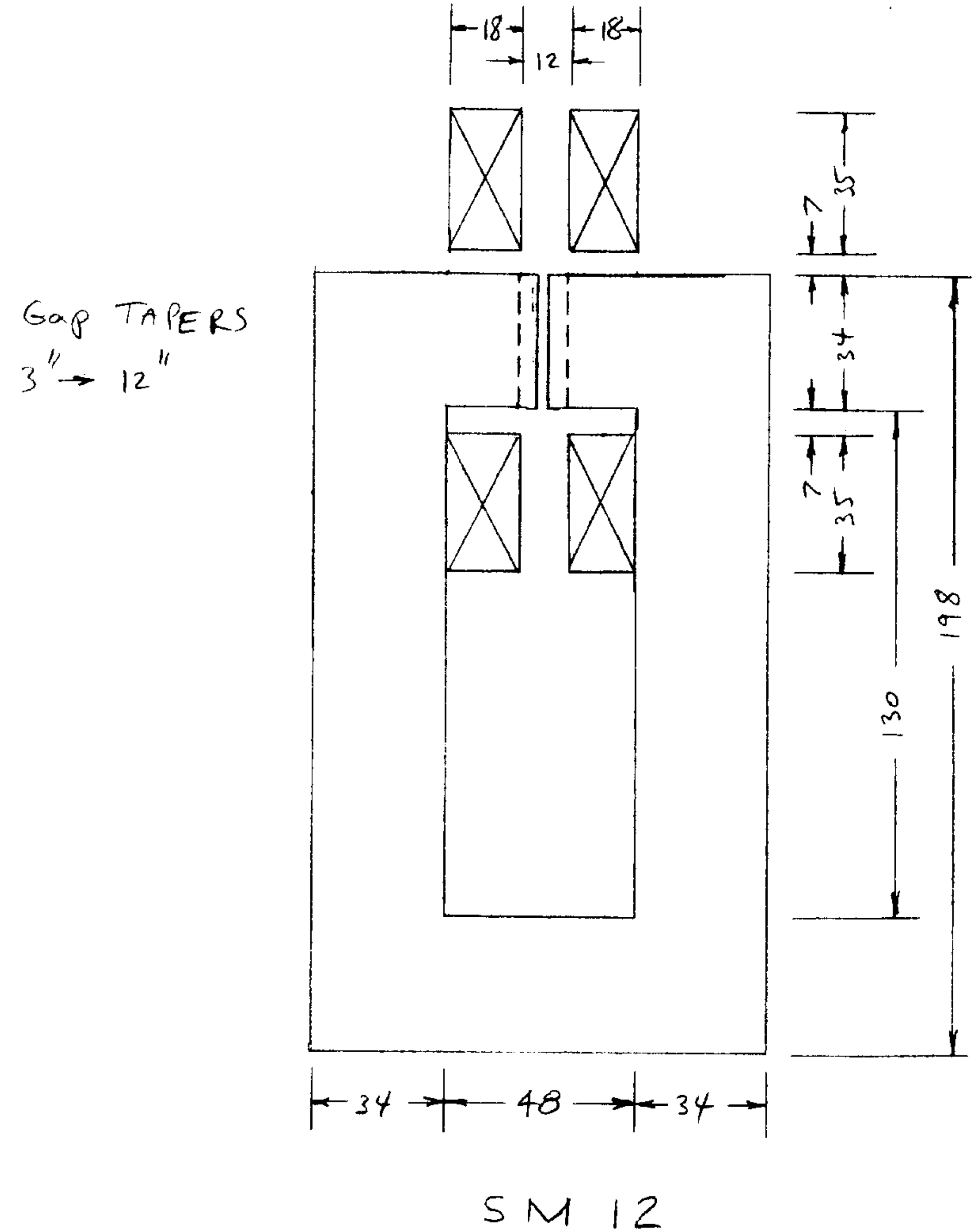
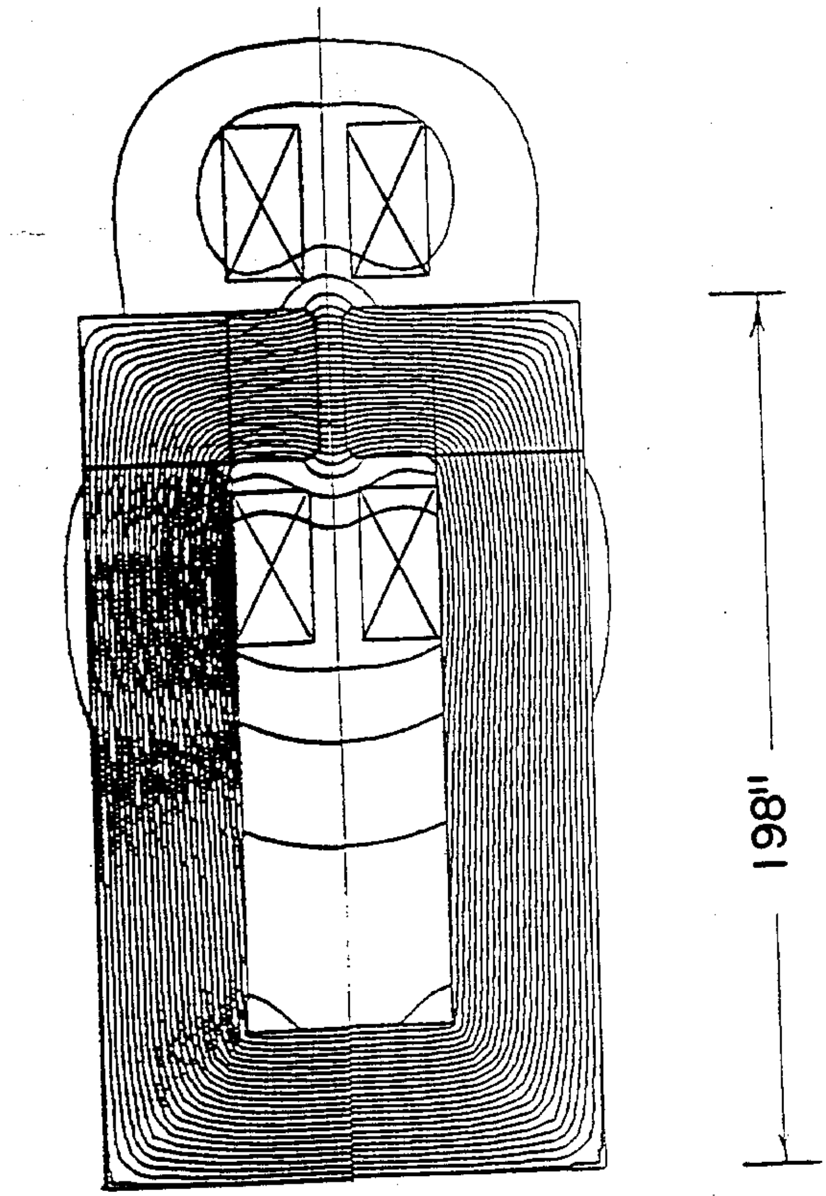


Figure 10. Cross section view of E605 magnet SM12 reconfigured as a C magnet. Dimensions are in inches.



SCALE 1:40

Figure 11



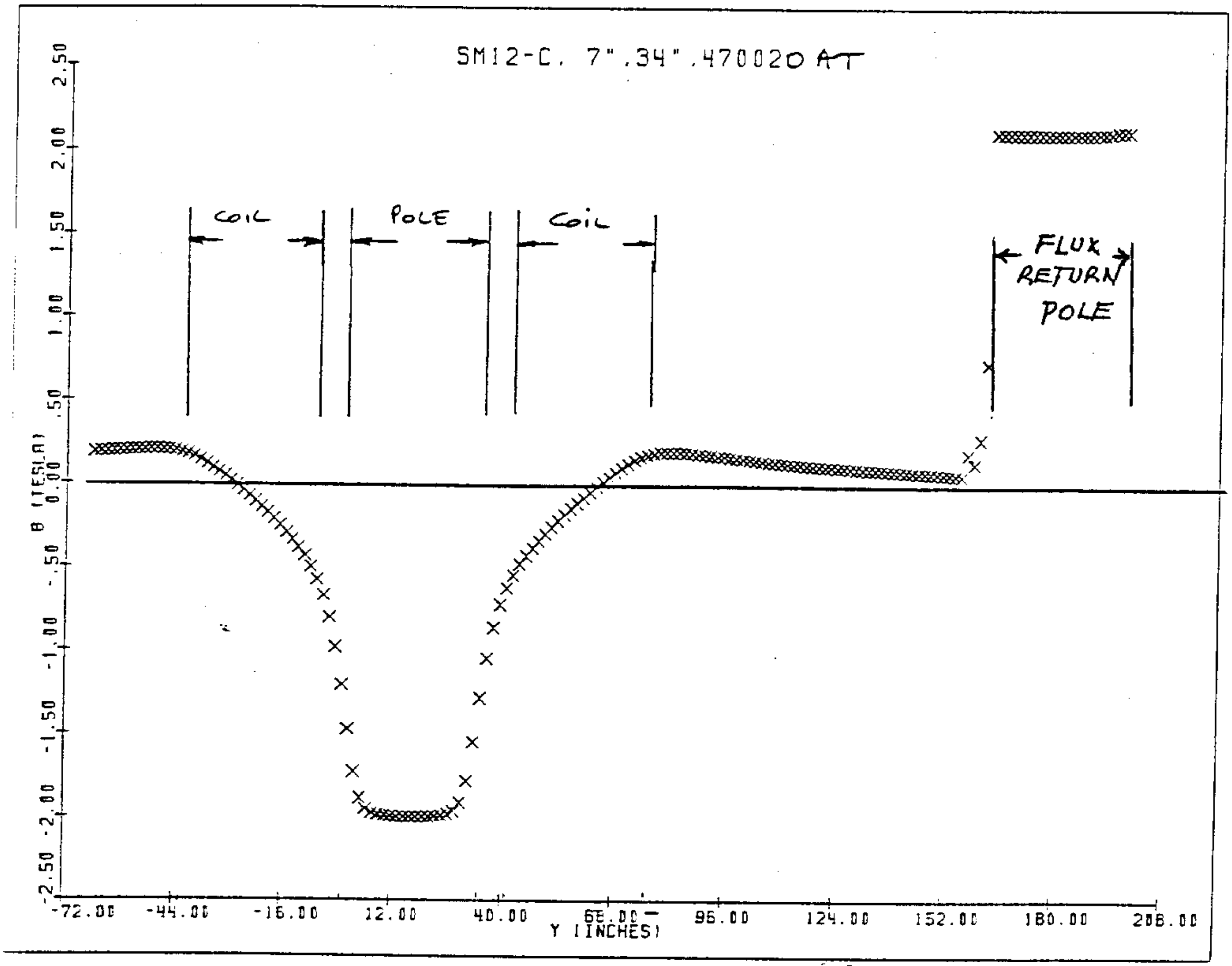
SM12-C

MAGNETIC FIELD

DISTRIBUTION

(7" GAP)

Figure 12



SM12-C, 7",34",470020 ~~AT~~
COIL
POLE
COIL
FLUX RETURN POLE
B (TESLA)
2.50
2.00
1.50
1.00
.50
0.00
-.50
-1.00
-1.50
-2.00
-2.50
-72.00
-44.00
-16.00
12.00
40.00
68.00
96.00
124.00
152.00
180.00
208.00
Y (INCHES)

Figure 13. Coulomb Bandpass Ray Trace

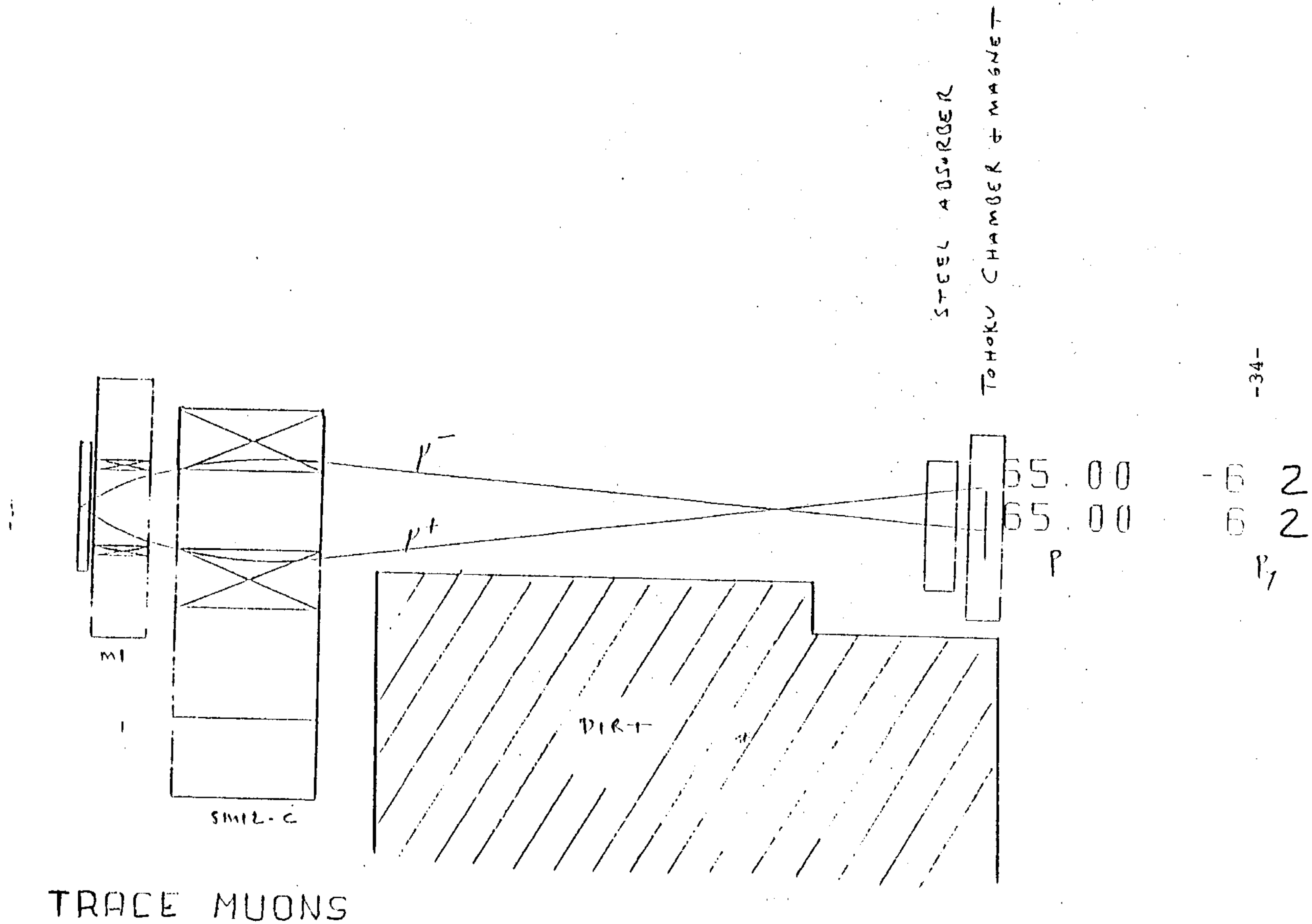


Figure 14

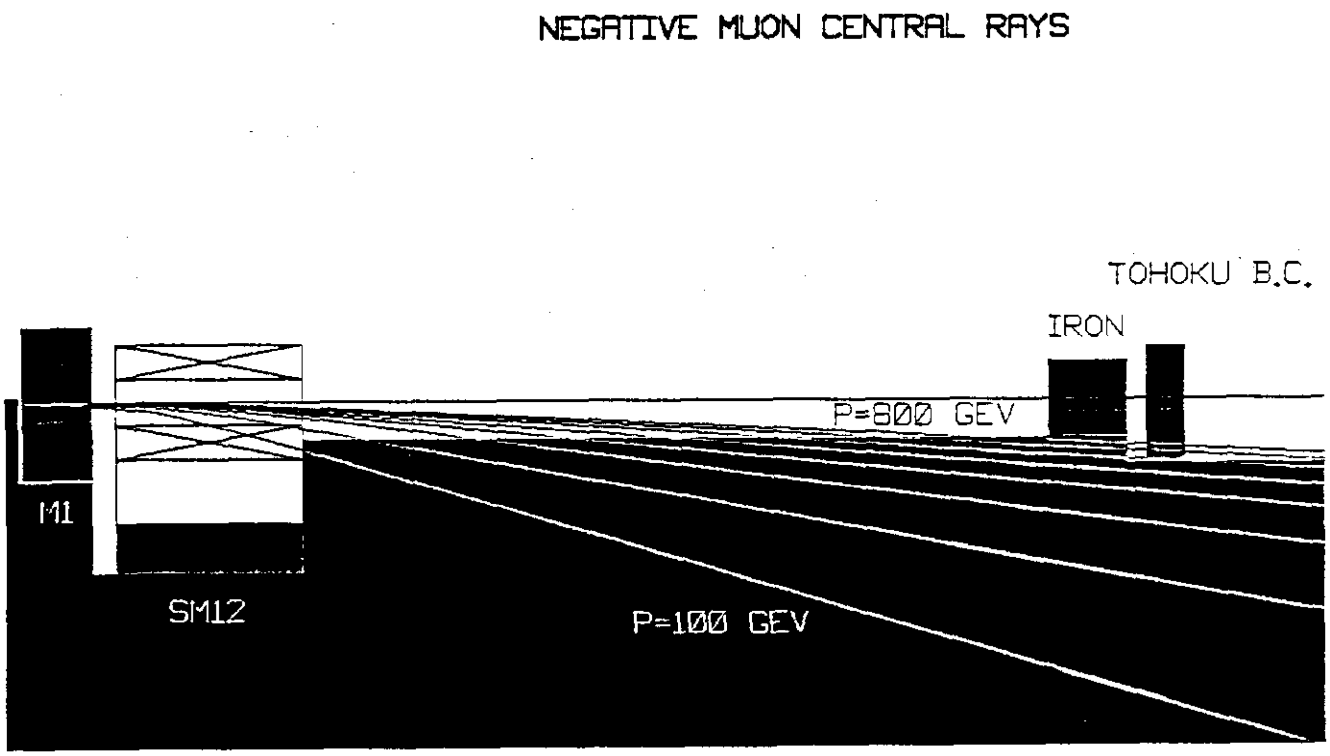
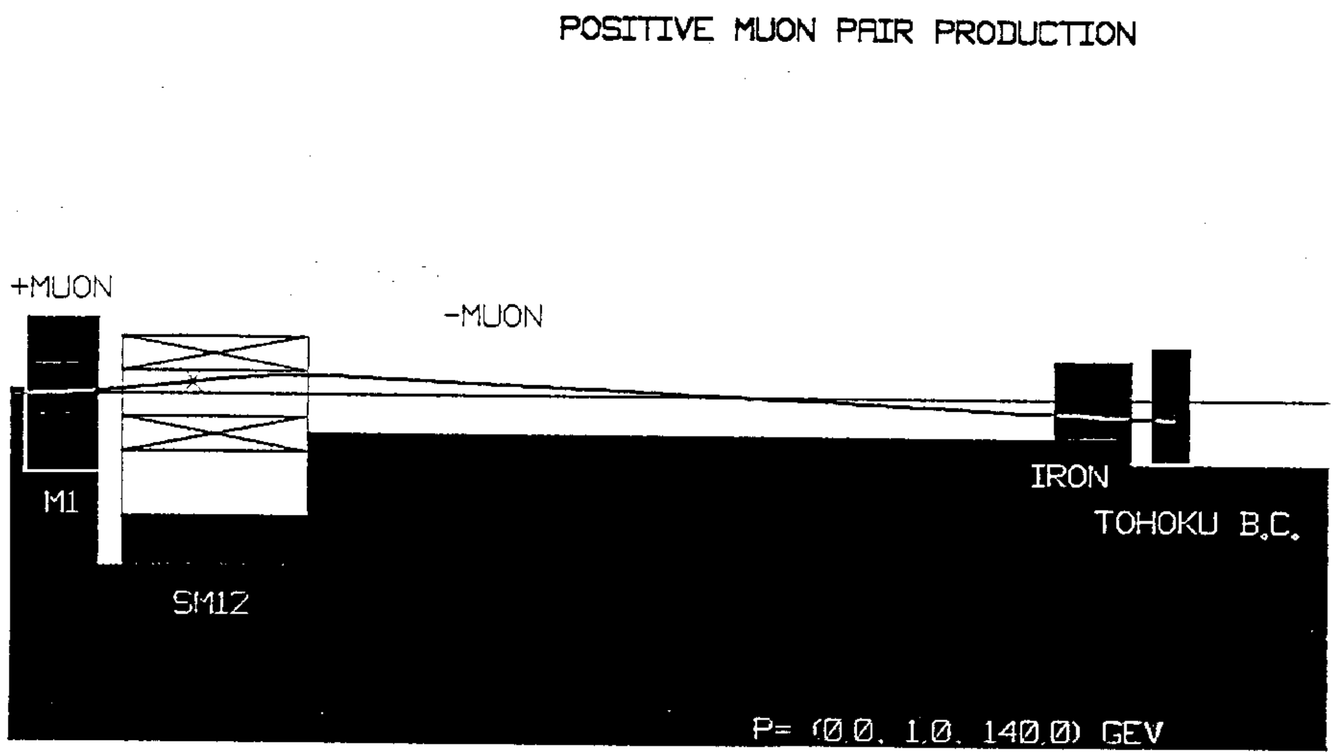

NEGATIVE MUON CENTRAL RAYS
TOHOKU B.C.
IRON
P=800 GEV
M1
SM12
P=100 GEV

Figure 15



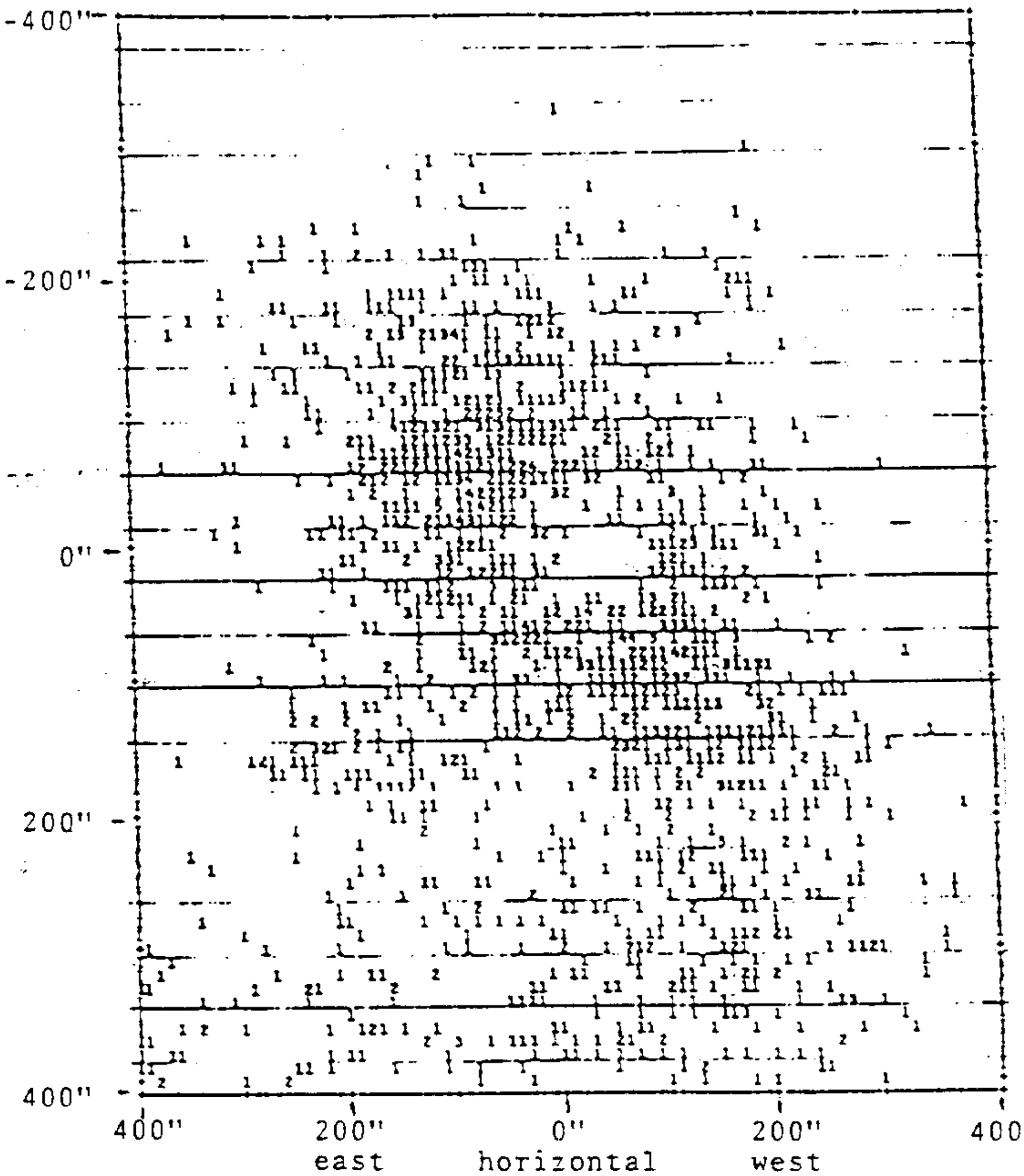
POSITIVE MUON PAIR PRODUCTION
+MUON
-MUON
M1
SM12
IRON
TOHOKU B.C.
P= (0.0, 1.0, 140.0) GEV

Figure 16

```
                        "ECONODUMP"
                         horizontal
       -400"      -200"       0"        200"      400"
-400"+----------+----L---------L-----+----L----+-----+ SUMS
     I                                               I
     I                                               I
     I                                               I
     I                                               I
     I                                               I
     I                                               I
     I                                               I
-200"I                                               I
     I                                               I
     +                                               +
     I                                               I
     I                         1                     I     1
     I                      11 1                     I     3
     I                      1 11 1                   I     4
     I                  1 131 541 1                  I    17
     I                    45BNRD534                  I    95
     I                  323B$$$W841                  I  1365
vertical 0"I             24EZ$$$D4                   I  1370
     I                   6149UFE71                   I    87
     +                    146312211                  +    21
     I                       2 111                   I     5
     I                   1   1                       I     2
     I                                               I
     I                                               I
     I                                               I
 200"I                                               I
     I                                               I
     I                                               I
     I                                               I
     +                                               +
     I                                               I
     I                                               I
     I                                               I
     I                                               I
 400"+---------+---------+---------+---------+-------+ SUMS
     S                 11                            S
     U                1331                           U
     M             114020131                         M
     S            41412513757                        S
```

Absorber at 1136' from beam dump. 6" radius pipe buried in berm. 1 entry = 1.928×10^6 positive muons. 5×10^5 parents at 900 GeV forced to decay at the absorber.

Figure 17



Positive muon sptial distribution in a plane transverse to the beam direction at the location of the tungsten target in Prompt Hall. The muons are procured by the interaction of 2.5 x 10^7 p's at the front of Encl. NE8. (Taken from Figure VI.2 of TM-1155 by C. Baltay et al.)

Figure 18

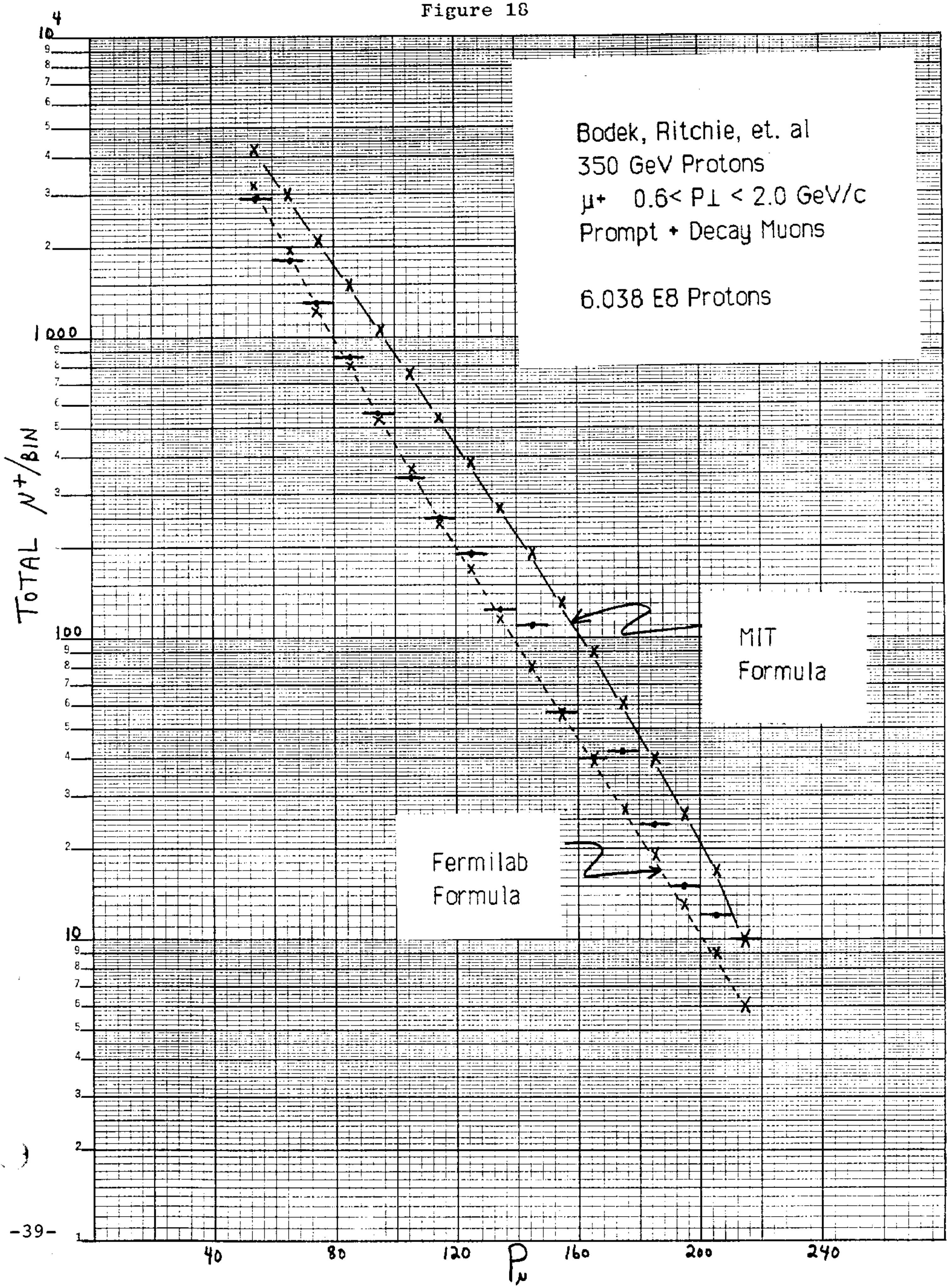

Bodek, Ritchie, et. al
350 GeV Protons
μ+ 0.6< P⊥ < 2.0 GeV/c
Prompt + Decay Muons
6.038 E8 Protons
MIT
Formula
Fermilab
Formula
TOTAL N+/BIN
10^4
1000
100
10
1
40
80
120
160
200
240
P_μ

Figure 19

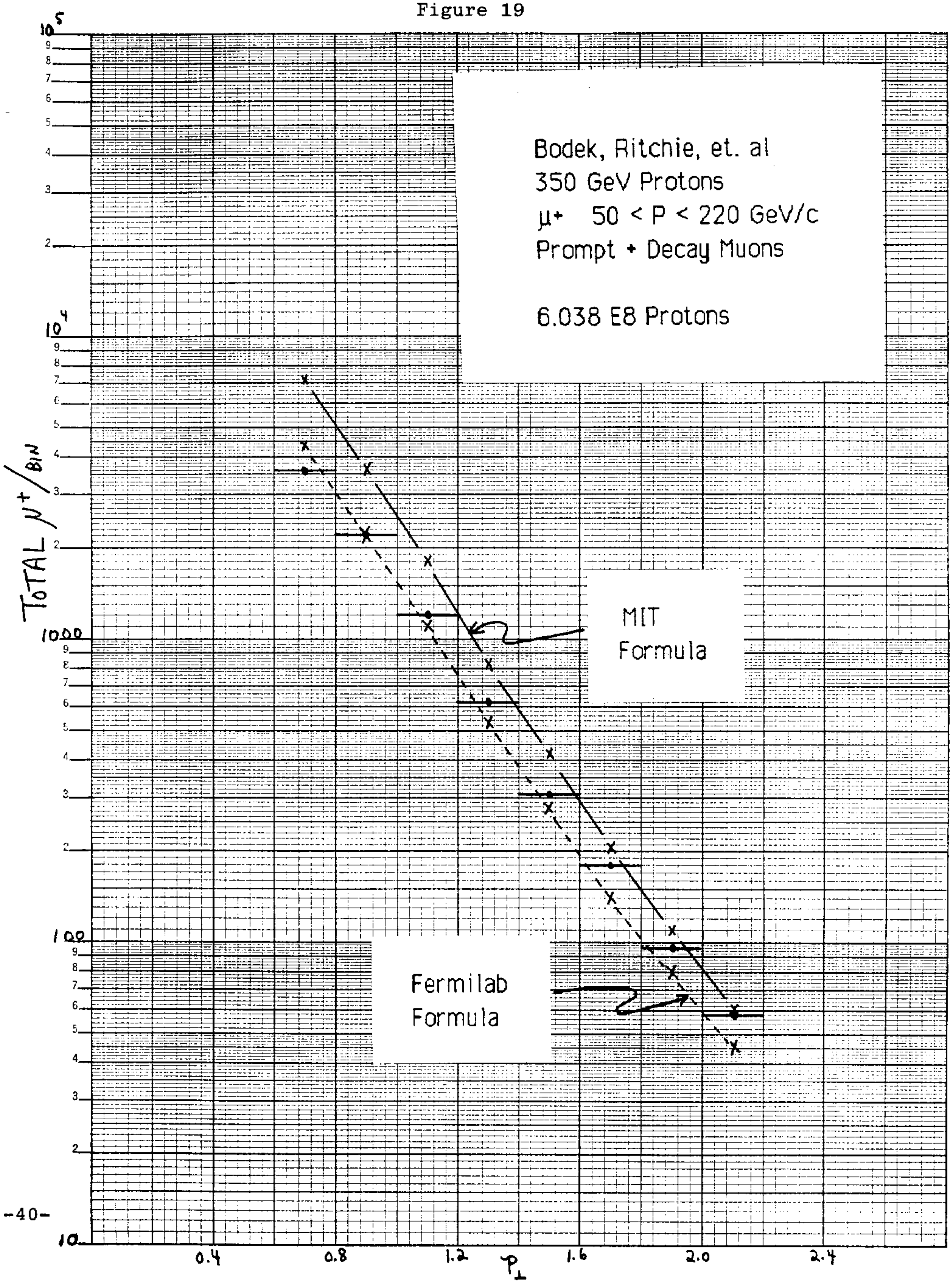
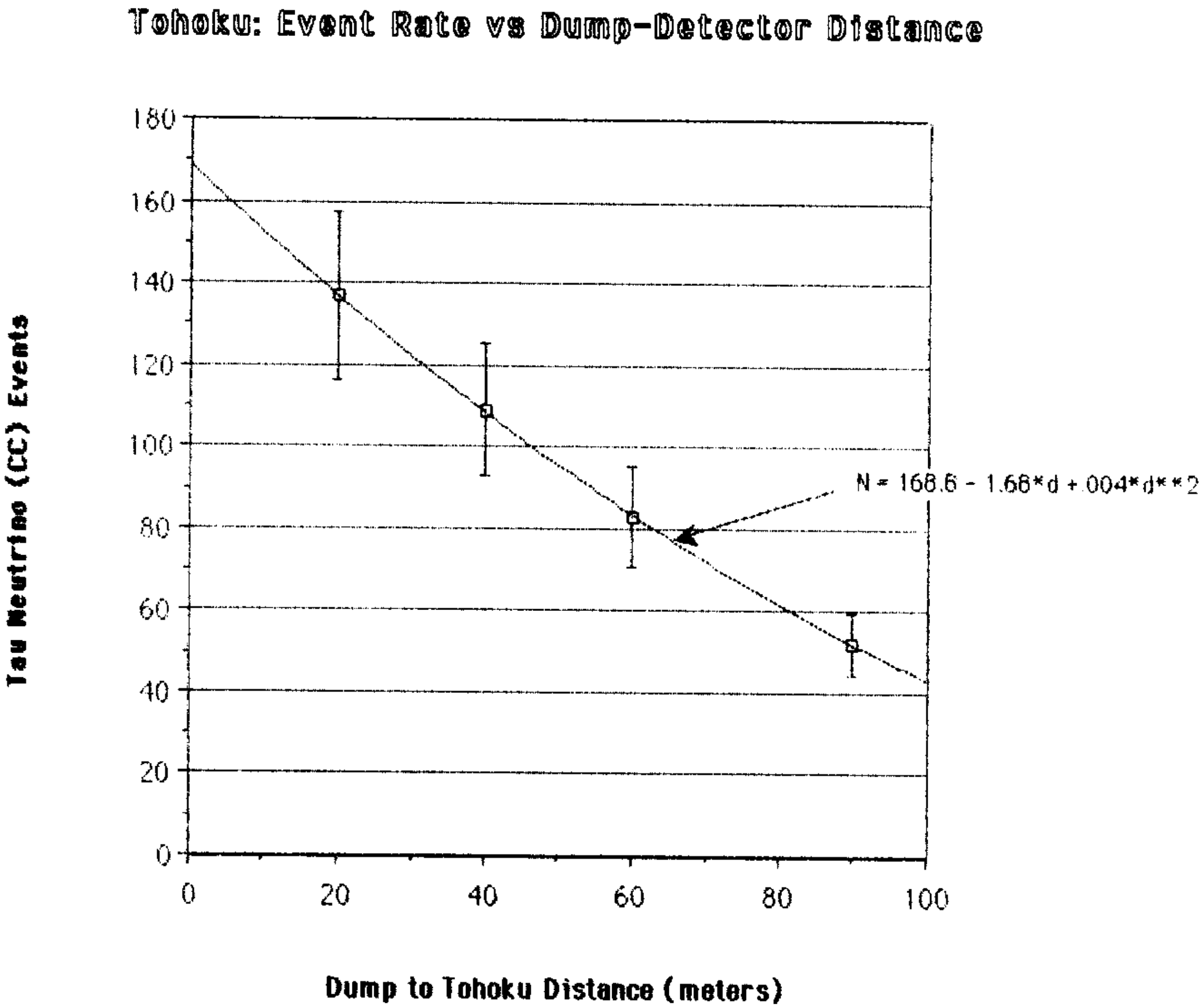

Bodek, Ritchie, et. al
350 GeV Protons
μ+ 50 < P < 220 GeV/c
Prompt + Decay Muons
6.038 E8 Protons
MIT
Formula
Fermilab
Formula
TOTAL μ+/BIN
P⊥
0.4
0.8
1.2
1.6
2.0
2.4
10
100
1000
10^4
10^5

Figure 20



Tohoku: Event Rate vs Dump-Detector Distance
Tau Neutrino (CC) Events
180
160
140
120
100
80
60
40
20
0
N = 168.6 - 1.68*d + .004*d**2
0
20
40
60
80
100
Dump to Tohoku Distance (meters)